FIRST BEAM TEST OF 81.5 MHZ RFQ FOR ITEP-TWAC

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Abstract

The 4 vane RFQ resonator with magnetic coupling windows as initial part of high-current Heavy Ion Linac for ITEP TWAC facility is presently under commissioning at ITEP. It was constructed for acceleration of ions with 1/3 charge to mass ratio to the energy of 1.57 MeV/u with beam current up to 100 mA. Additional beam dynamics simulations have been carried out for actual fields of the RFQ in order to determine both extreme output beam properties for different ion species with charge to mass ratio in the range of 1-0.25 and limitations for high-brightness of the high-current injector. The beam test of RFQ has been started with protons at relatively low electrode voltage for experimental studying the RFQ beam dynamics in the wide range of rf power operation. First results of the beam test in comparison with beam dynamics simulations are presented.

INTRODUCTION

The proton-ion ITEP-TWAC accelerator-accumulator complex [1] consisting of main synchrotron-accumulator U-10 with 25 MeV proton injector I-2 and booster synchrotron UK with 4 MV ion injector I-3 runs now in several operation modes accelerating protons in the energy range of 0.1-9.3 GeV, accelerating ions in the energy range of 0.1-4 GeV/u and accumulating nuclei up to Cu at the energy of 200-400 MeV/u.

The new high current ion injector I-4 for acceleration of ions with charge-to-mass ratio 1/3 to the energy of 7 MeV/u and beam current up to 100 mA will allow increasing intensity of the ion beam in UK Ring to reach the terawatt level of stacked beam power in storage ring U-10.

The 81.5 MHz RFQ with output energy of 1.57 MeV/u [2] as first part of I-4 is presently under commissioning. The design of the second part (IH-DTL) [3] which will provide output energy of 7 MeV/u is also going on. The first beam test was carried out with protons for experimental studying of beam dynamics in the wide range of rf power in resonator and to evaluate actual inter-electrode voltage achieved during conditioning the resonator.

RESULTS OF BEAM DYNAMICS SIMULATION

Design of the 81.5 MHz RFQ cavity is based on 4-vane resonator with magnetic coupling windows (MCW). Since the windows on adjacent vanes have been displaced with respect each other, for increasing magnetic coupling, an electric field (E_z) appears on beam axis in the gaps between flanges and the vanes. Originally, the simulation of the beam dynamics was carried out by using code "DYNAMION" elaborated in ITEP. Additional beam dynamics study for actual fields of the RFQ was performed with a new code "TRANSIT" which is an advanced version of the" DYNAMION". The measured inter-electrode voltage distribution V(z) along the RFQ structure that was used for simulation is shown in Fig. 1. The azimuthal voltage unbalance among the four quadrants is within +/-1%. The tilt of voltage curve to the end of resonator is near of 10%. The reason of the tilt was found as result of increasing average aperture radius to the end of the RFQ. Since azimuthal distribution, which has rather strong impact on beam dynamics, was pretty good and resonant frequency of the RFQ was already higher than 81.5 MHz, making impossible usage of rf tuners, the decision has been taken to start beam test without equalizing longitudinal distribution, meaning to do it later.

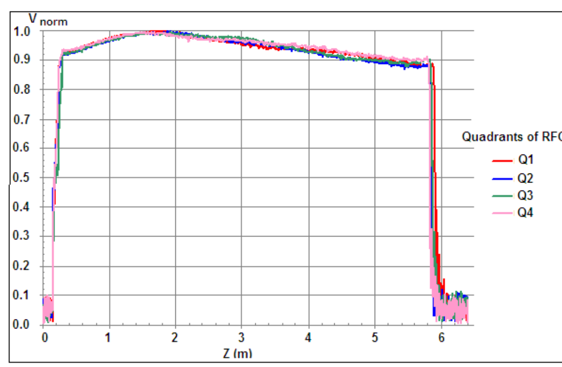

Figure 1: Inter-electrode voltage distribution V(z).

The space between inlet flange and edges of the electrodes was considered as a drift space for the beam in the first simulations. The new study has been performed taking into account electromagnetic fields in the gap. Figure 2 depicts the electric field (E_z) on the axis for the both cases.

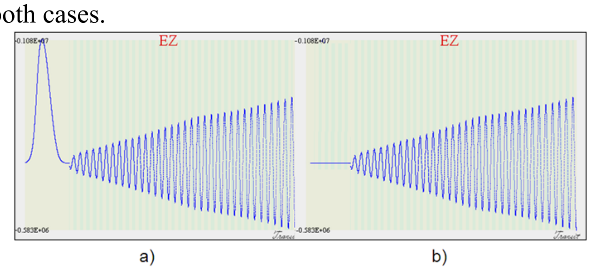

Figure 2: Distributions of E_z on inlet of the RFQ for actual case (a) compared with drift space case (b).

In order to evaluate impact of inter-electrode voltage distribution along the RFQ (V(z)) on the beam dynamics, the simulations were performed for ideal (V(z) = const) and for actual distribution V(z), achieved after alignment

(Fig. 1). Results of beam dynamics simulation for the matched beam with zero current through the ideal RFQ structure at nominal inter-electrode voltage V=182.5 kV is shown on Fig. 3. The transmission is >99% for the output beam with unnormalized emittance $\varepsilon_{x,y}$~20 mm mrad, energy half-spread of ~2.5% and bunch length of ~40°.

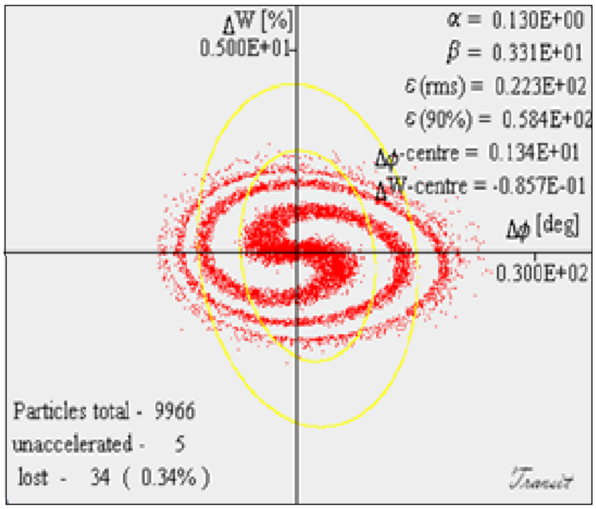

Figure 3: The output beam longitudinal emittance for ideal RFQ stucture.

For the real inter-electrode voltage distribution (Fig. 1), the same transmission (>99%) can be obtained for the output beam with similar emittance, similar energy half-spread of ~2.5%. But a "tail" appears in longitudinal emittance (Fig. 4) due to reducing longitudinal acceptance in high energy RFQ part. Increasing the inter-electrode voltage by ~5% allows to compensate this effect. For both cases no fields in the gap between flange and electrodes, were included in the simulation (drift case).

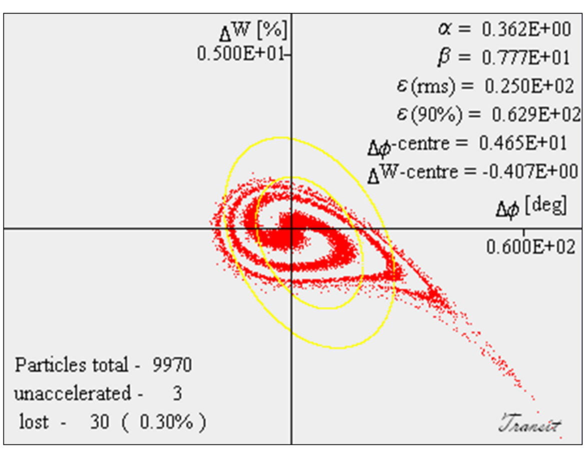

Figure 4: The output beam longitudanal emittance for actual inter-electrode voltage distribution V(z).

As it was mentioned above, original 4-vane RFQ and MCW structure have different field distribution in the space between end plates and the electrodes. That is why, special attention was paid to the impact of the longitudinal electric fields in the input gap on beam dynamics. Note, that longitudinal component of electric field (E_z) in the gap of 4-vane RFQ is equal zero only on beam exis and on two mutually perpendicular planes rotated on 45° with respect to vertical (horizontal) axis of the resonator. For example, Fig. 5 depicts component E_z of the electric field along the structure, outside the axis (x = 0; y = 5 mm), taken from electrodynamic simulation, for original 4-vane RFQ having both the same input geometry and the same resonant frequency as MCW structure.

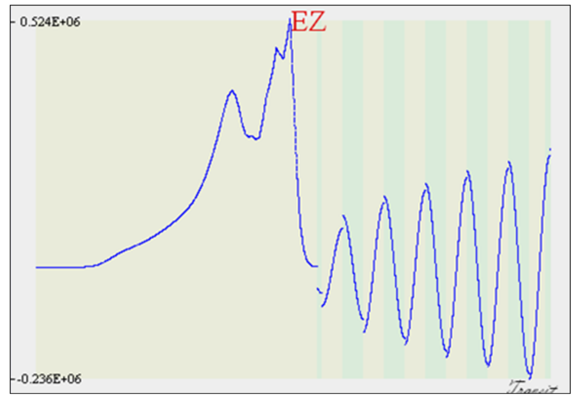

Figure 5: $E_z(z)$ distribution of 4-vane RFQ outside beam axis.

The beam dynamic study of ITEP RFQ with fields in the gap, extracted from electrodynamic simulation, and V(z) distribution (Fig. 1) increased by 5% to compensate effect of the "tail", was performed. Initial matched Twiss parameters were the following: $\alpha_{x,y}$ = 1.47, $\beta_{x,y}$ = 0.021 mm/mrad, and $\varepsilon_x = 270\ \pi$ mm mrad.

Results of the simulation are shown in Fig. 6.

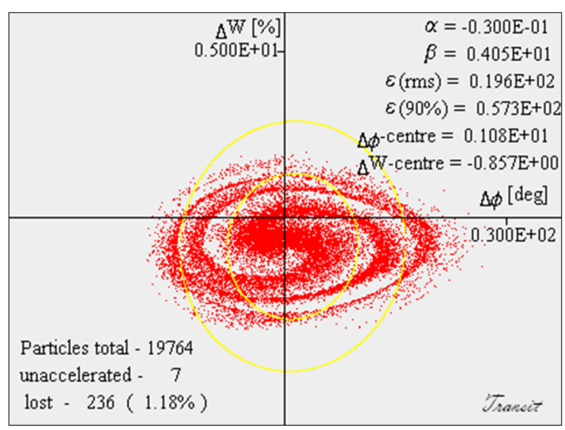

Figure 6: The output beam longitudanal emittance for field in the gap real increased by 5% V(z) in the RFQ.

For comparison, Fig. 7 depicts results of beam dynamic simulation of MCW RFQ for the drift case in the gap and actual inter-electrode voltage distribution (Fig. 1) with initial Twiss parameters: $\alpha_{x,y}$ = 1.2, $\beta_{x,y}$ = 0.017 mm/mrad, and $\varepsilon_x = 270\ \pi$ mm mrad. Comparing Fig. 6 and Fig. 7 one can see that fields in the gap (Fig. 6) result in small increasing particles losses to 1.18%, increasing output beam emittance to $\varepsilon_{x,y}$~40 mm mrad and energy spread similar to that shown in Fig. 4.

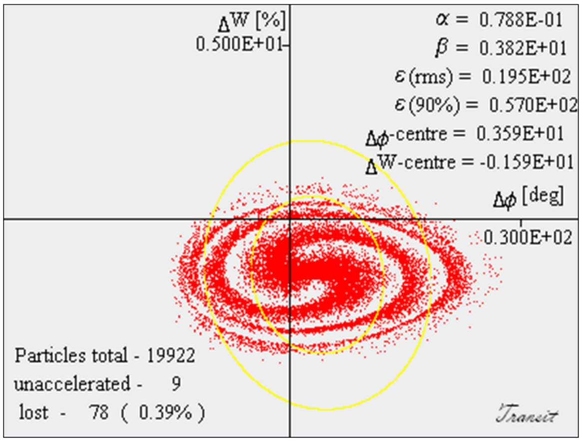

Figure 7: The output beam longitudanal emittance for for drift case and real increased by 5% V(z) in the RFQ.

The difference is negligible, if to take into account that final result depends on the accuracy of initial beam parameters. Simulations carried out for 4-vane RFQ having the same input geometry as MCW structure showed practically the same result.

So, results of the simulations confirmed that there is no serious impact of the longitudinal electric fields in the space between input flange and electrodes on beam dynamics.

BEAM TEST OF THE RFQ

Configuration of RFQ section with ion source of duoplasmatron type was assembled for experiments on proton beam acceleration at variable rf power in resonator and input beam parameters.

First beam test was done with the rf pulse duration of 200 µs at repetition rate of 0.25 Hz. The current pulse width was ~20 µs (Fig. 8). Small current from ion source was used in order to minimize the impact of Coulomb forces on beam dynamics. The 10 µm aluminium foil was installed on outlet of the RFQ in order to select accelerated particles with energy >0.8 MeV/u. Accelerated bunched beam was observed on Faraday cup installed after the aluminium foil at the rf power level of 0.8 of the nominal value as it was expected from the simulation. Increasing rf voltage to the nominal value, the beam current with amplitude of ~4 mA was obtained on outlet of the RFQ (Fig. 9). Acceleration of proton beam showed the actual inter-electrode voltage which is needed for ion acceleration. Evaluation of maximal rf voltage achieved in resonator during conditioning gives the value close to nominal 182.5 kV which is practically sufficient to accelerate ions with Z/A=1/3. However, for reliable operation it will be necessary to increase inter-electrode voltage at least on 10%.

Low Enegy Beam Transfer (LEBT) line for ions with Z/A=1/3 is being manufactured for the moment. Rather simple LEBT was used for the proton beam test, containing minimum beam diagnostics on imput of RFQ and hence no evaluation of the RFQ transmission was carried out.

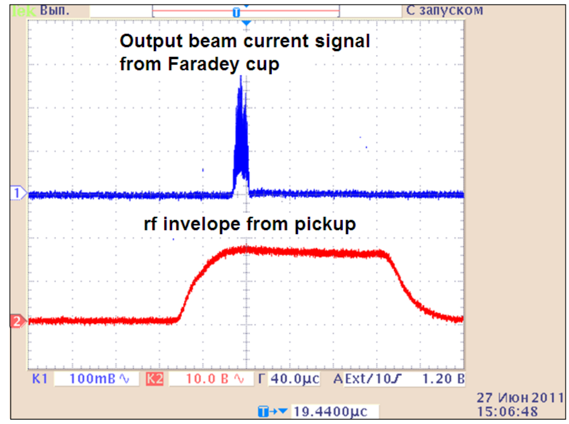

Figure 8: RF envelope and accelerated beam current.

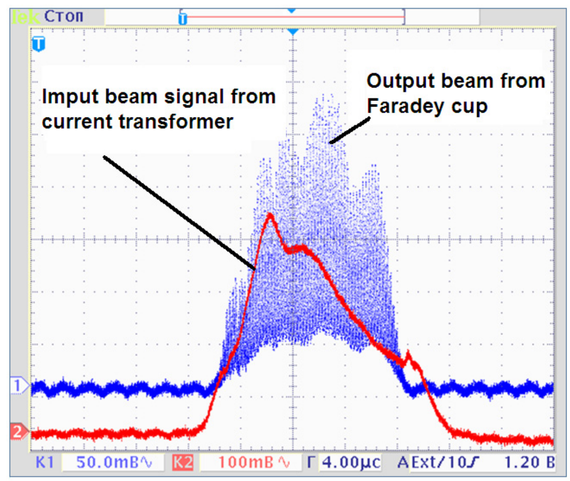

Figure 9: Beam current on inlet and outlet of RFQ.

CONCLUSION

The first beam was successfully accelerated in the new 81.5 MHz RFQ in ITEP, which is first in the world RFQ with coupling windows. It allowed evaluating the inter-electrode voltage achieved during resonator conditioning. We are going to improve beam diagnostics on input of RFQ in order to define real transmission of the RFQ structure, equalize inter-electrode voltage distribution along the structure and continue commissioning the RFQ

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